

**GEMINI RELIABILITY AND QUALIFICATION EXPERIENCE**

by

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## FOREWORD

This paper is an edited version of an earlier paper entitled "Spacecraft Reliability and Qualification" which was presented at the Gemini Mid-Program Conference at NASA Manned Spacecraft Center, Houston, Texas on February 23 to 25, 1966. The authors of the original paper were:

W. Harry Douglas, formerly Deputy Manager, Office of Test Operations, Gemini Program Office, NASA Manned Spacecraft Center, and now Manager, Test Operations Office for the Apollo Applications Program Office, NASA Manned Spacecraft Center.

Gregory P. McIntosh, Gemini Program Office, NASA Manned Spacecraft Center.

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This paper differs from the original presentation in that the emphasis has been placed on the guidance and control system of the Gemini spacecraft.

This paper is to be presented before the NATO Advisory Group for Aeronautical Research and Development, Guidance and Control Panel Symposium, Paris, France on March 7 and 8, 1967.

# GEMINI RELIABILITY AND QUALIFICATION EXPERIENCE

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## 1. SUMMARY

The Gemini reliability and qualification program was based on conventional concepts. However, these concepts were modified with unique features to obtain the reliability required for manned space flight and to optimize the reliability and qualification effort.

Emphasis was placed on establishing high inherent reliability and low crew-hazard characteristics early in the design phases of the Gemini Program. Concurrently, an integrated ground test program was formulated and implemented by the prime contractor and the major suppliers of flight hardware. All data derived from all tests were correlated and used to confirm the reliability attained.

Mission-success and crew-safety design goals were established contractually, and estimates were made for each of the Gemini missions without conducting classical reliability mean-time-to-failure testing.

Design reviews were conducted by reliability engineers skilled in the use of reliability analysis techniques. The reviews were conducted independently of the designers to insure unbiased evaluations of the

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\*Other contributors to this paper were Gregory P. McIntosh and Lemuel S. Menear, NASA Manned Spacecraft Center, Houston, Texas.

design for reliability and crew safety and were completed prior to specification approval and the release of production drawings.

An ambitious system to control quality was rigidly enforced to attain and maintain the reliability inherent in the spacecraft design.

A closed-loop failure-reporting and corrective-action system was adopted which required the analysis, determination of the cause, and corrective action for all failures, malfunctions, or anomalies.

The integrated ground test program consisted of development, qualification, and reliability tests and was conducted under rigid quality-control surveillance. This test program, coupled with two unmanned Gemini flights, qualified the spacecraft for manned flights.

## 2. INTRODUCTION

Approximately 6 years ago, men ventured briefly into space and returned safely. These initial manned space flights were, indeed, tremendous achievements which stirred the imagination of people worldwide. They also served to provide a focus for the direction of future efforts. Gemini was the first United States manned space flight program that had the opportunity to take this early experience and carry out a development, test, and flight program in an attempt to reflect the lessons learned.

The level of reliability and crew safety, attained in the Gemini spacecraft and demonstrated during the 12 Gemini missions, is the result of a concerted effort by contractor and customer engineers,

technicians, and management personnel working together as one team within a management structure which permitted an unrestricted exchange of information and promoted a rapid decision-making process.

Stringent numerical design goals for Gemini mission success and crew safety were placed on the spacecraft contractor who incorporated these goals in each specification written for flight hardware. To meet this specification requirement, the suppliers had to give prime consideration to the selection, integration, and packaging of component parts into a reliable end item. Reliability analyses were required from the major equipment suppliers to assess the design for the inherent capability of meeting the established design goal.

The spacecraft contractor was required to integrate the subcontractor-supplied hardware and to effect the necessary redundancy in the spacecraft to meet the overall reliability goal.

Examples of the spacecraft redundant features were:

(1) Duplicate horizon sensors were incorporated in the guidance system.

(2) Every function in the pyrotechnic system incorporated a redundant feature.

(3) Two completely independent reentry-control propulsion systems were installed in the spacecraft.

(4) Redundant coolant subsystems were incorporated in the environmental control system.

(5) Six fuel-cell stacks were incorporated in the electrical system although only three are required for any long-duration mission.

Redundant systems or backup procedures were provided where a single failure could be catastrophic to the crew or the spacecraft.

Concurrent with design and developments, an integrated ground test program was established. Data from all tests were collected and analyzed to form a basis for declaring the Gemini spacecraft qualified for the various phases of the flight test program. The value of the integrated ground test program can best be appreciated by viewing figure 1, which shows the density of the test effort with respect to the production of the flight equipment. The high level of ground test effort commenced at the outset of the program and was sustained past the first several flights. The ability to fly with some qualification testing underway is related to the differences between the early spacecraft configurations and the long-duration and rendezvous spacecraft configurations. It was hoped that the ground testing could be completed earlier, but the problems that were isolated and the required corrective action prevented earlier accomplishment. In spite of the great effort involved, it was better to utilize a ground test program to ferret out problems than to encounter them in flight.

Development tests were initially performed to prove the design concepts. Qualification tests were conducted to prove the flight configuration design and manufacturing techniques. Tests were then extended beyond the specification requirements to establish reasonable design

margins of safety. The unmanned flight tests were conducted to confirm the validity of design assumptions and to develop confidence in spacecraft systems and launch-vehicle interfaces prior to manned flights.

Specific test-program reviews were held at the prime contractor's plant and at each major subcontractor's facility to preclude duplication of testing and to insure that every participant in the Gemini Program was following the same basic guidelines.

### **3. MISSION SUCCESS AND CREW SAFETY**

A numerical design goal was established to represent the probability of the spacecraft performing satisfactorily for the accomplishment of all primary mission objectives. The arbitrary value of 0.95, which recognizes a risk of failing to meet 1 primary objective out of 20 on each mission, was selected. The 0.95 mission-success design goal was included in the prime contract as a design goal rather than a firm requirement, which would have required demonstration by mean-time-to-failure testing. The prime contractor calculated numerical apportionments for each of the spacecraft systems and incorporated the apportioned values in major system and subsystem contractor requirements. Reliability estimates, derived primarily from component failure-rate data and made during the design phase, indicated that the design would support the established design-mission success goal. The reliability estimates, by major spacecraft system, for the Gemini III spacecraft, are shown in table I.

Crew safety design goals were also established, but for the much higher value of 0.995 for all missions. Crew safety was defined as having the flight crew safely survive all missions or all mission attempts.

Planned mission success, gross mission success, and crew safety estimates were also made prior to each manned mission, using the flight data and data generated by the integrated ground test program; each estimate reflected assurance of conducting the mission successfully and safely.

A detailed failure mode and effect analysis was conducted on the complete spacecraft by the prime contractor, and on each subsystem by the cognizant subcontractor, to investigate each failure mode and assess its effect on mission success and crew safety. The analysis included an evaluation of:

- (1) Mode of failure
- (2) Failure effect on system operation
- (3) Failure effect on the mission
- (4) Indications of failure
- (5) Crew and ground action as a result of the failure
- (6) Probability of occurrence

Corrective action was taken when it was determined that the failure mode would grossly affect mission success or jeopardize the safety of the crew.



A single-point failure mode and effect analysis was conducted for all manned missions to isolate single failures which could prevent recovery of the spacecraft or a safe recovery of the crew. The single-point failure modes were evaluated, and actions were taken to eliminate the single-point failure or justify the design adequacy, and to prescribe the necessary precautions to minimize the probability of occurrence.

#### 4. DESIGN REVIEWS

Critical reliability design reviews were conducted as soon as the interim design was established. The reviews were conducted by reliability personnel, independent of the designer, and resulted in recommended changes to improve the reliability of all the respective systems or subsystems. The reviews included the use of:

- (1) Numerical analyses
- (2) Stress analyses
- (3) Analyses of failure modes
- (4) Trade-off studies to evaluate the need for redundant features

A typical design change is shown schematically in figure 2. This change was incorporated because the 2-day Gemini rendezvous flight required four of the six fuel-cell stacks, three stacks to a section, to meet mission objectives. The failure of a single supply pressure regulator would have caused the loss of a fuel-cell section. Therefore, it was necessary that each of the two regulators which control the reactant

supply be capable of supplying reactants to both fuel-cell sections. The crossover provided this capability. Figure 3 shows the electrical power system reliability slightly increased for the 2-week mission. The reliability was increased from 0.988 to 0.993 for an assumed failure rate of  $10^{-4}$  failures per hour. Figure 4 shows the reliability greatly increased for the 2-day mission.

It cannot be overemphasized that reliability is an inherent characteristic and must be realized as a result of design and development. Inherent reliability cannot be inspected or tested into an item during production. At best, that which is inherent can only be attained or maintained through rigid quality control. These reliability design reviews and the numerical analyses were conducted as early as November 1962, prior to the fabrication of the first production prototypes.

## 5. DEVELOPMENT TESTS

Development tests using engineering models were conducted to establish the feasibility of design concepts. These tests explored various designs and demonstrated functional performance and structural integrity prior to committing production hardware to formal qualification tests.

In some cases, environmental tests were conducted on these units to obtain information prior to the formal qualification.

## 6. INTEGRATED SYSTEM TESTS

Integrated system tests were conducted during progressive stages of the development to demonstrate the compatibility of system interfaces. Such systems as the inertial guidance system, the propulsion system, and the environmental control system were especially subjected to such tests. Early prototype modules were used in static articles or mockups, which represented complete or partial vehicles. They served to acquaint operating personnel with the equipment and to isolate problems involving electrical-electronic interface, radiofrequency interference, and system-design compatibility.

When production prototype systems became available, a complete spacecraft compatibility test unit was assembled at the prime contractor's facility (fig. 5). During these tests, system integration was accomplished by end-to-end test methods. These tests permitted the resolution of problems involving mechanical interface, electrical-electronic interference, radiofrequency interference, spacecraft compatibility, final test procedures compatibility, and compatibility with aerospace ground equipment (AGE), prior to assembly and checkout of the first flight vehicle.

One of the more significant integrated system tests was the thermal qualification or the spacecraft thermal-balance test. This test was

conducted on a complete production spacecraft. Tests were conducted in a cold-wall altitude chamber that simulated altitude and orbital heating characteristics with the spacecraft powered.

The test results demonstrated the need for heating devices on the propulsion system and on water lines to prevent freezing conditions during the long duration mission.

## **7. SYSTEM QUALIFICATION TEST**

Because flying all-up manned space vehicles is expensive, time consuming, and exceedingly critical to failures, the Gemini development was based on the premise that confidence could be achieved through a properly configured program of ground tests and that a very limited number of unmanned flights could serve to validate the approach.

Each item of spacecraft equipment was qualified prior to the mission on which the item was to be flown. The equipment was considered qualified when sufficient tests had been successfully conducted to demonstrate that a production unit, produced by production personnel and with production tooling, complied with the design requirements. These tests included at least one simulation of a long-duration flight, or one rendezvous mission, or both, if necessary, with the system operating to its expected duty cycle.

Qualification requirements were established and incorporated in all spacecraft equipment specifications. The specifications imposed varied

requirements on equipment, depending on the location of the equipment in the spacecraft, the function to be performed by the equipment, and the packaging of the equipment.

The environmental levels to which the equipment was subjected were based on anticipated preflight, flight, and postflight conditions. However, the environmental levels were revised whenever actual test or flight experience revealed that the original anticipated levels were unrealistic. This is exemplified by:

(1) The anticipated launch vibration requirement for the spacecraft was based on data accumulated on Mercury-Atlas flights. The upper-two sigma limit of these data required a power spectral density profile of approximately 12g random vibration. This level was revised because the Gemini I flight demonstrated that the actual flight levels were less than expected. The new data permitted the power spectral density to be changed, and by using the upper-three sigma limit the requirement was reduced to an overall rms acceleration level of 7g random in the spacecraft adapter and to 8.8g random in the reentry module.

(2) An aneroid device used in the personnel parachute was expected to experience a relatively severe humidity; therefore, the qualification test plan required the aneroid device to pass a 10-day 95-percent relative humidity test. The original design of the aneroid device could not survive this requirement and was in the process of being redesigned when the Gemini IV mission revealed that the actual humidity in the spacecraft cabin was considerably lower than expected. The requirement was

reduced to an 85-percent relative humidity, and the new aneroid device successfully completed qualification.

(3) The tank bladders of the propulsion system did not pass the original qualification slosh tests. Analyses of the failures concluded that the slosh tests conducted at one g were overly severe relative to actual slosh conditions in a zero-g environment. The slosh test was changed to simulate zero-g conditions more accurately, and the slosh rate was reduced to a realistic value. The tests then were repeated successfully under the revised test conditions.

The development and timely execution of a realistic qualification program can be attributed, in part, to a vigorous effort by government and contractor personnel conducting test-program reviews at the major subcontractor plants during the initial qualification phase of the program. The objective of the reviews was to align the respective system test program to conform to an integrated test philosophy. The original test reviews were followed with periodic status reviews to assure that the test programs were modified to reflect the latest program requirements and to assure the timely completion of all testing which represented constraints for the various missions.

Figure 6 is a block diagram of the Gemini guidance and control system. The qualification test environments required for the digital command system are shown in table II. These data were extracted from the spacecraft qualification status report, and show the qualification status. Although the digital command system did not experience all the

environments shown here, the data provide a typical example of the Gemini guidance and control component qualification test requirements. All environmental requirements were not applicable since the digital command system was located in the adapter and did not experience such environments as oxygen atmosphere and salt-water immersion. Those environments which were required are noted with a C or S in the appropriate column. The C designates that the equipment has successfully completed the test, and the S designates that the equipment has been qualified by similarity. A component or assembly is considered qualified by similarity when it can be determined by a detailed engineering analysis that design changes have not adversely affected the qualification of the item.

## 8. RELIABILITY TESTING

For programs such as Gemini, which involve small production quantities, the inherent reliability must be established early in the design phase and realized through a strict quality control system. It was not feasible to conduct classical reliability tests to demonstrate equipment reliability to a significant statistical level of confidence. Consequently, no mean-time-to-failure testing was conducted. Confidence in Gemini hardware was established by analyzing the results of all test data derived from the integrated ground and flight test program, and by conducting additional reliability tests on selected components and systems whose functions were considered critical to successful mission accomplishment.

Equipment was selected for reliability tests after evaluating the more probable failure modes. The tests were designed to confirm the design margins or to reveal marginal design characteristics, and they included exposure to environmental extremes such as:

- (1) Temperature and vibration beyond the design envelope
- (2) Applied voltage or pressure beyond the normal mission condition
- (3) Combined environments to produce more severe equipment stress
- (4) Endurance beyond the normal mission duty cycles

The reliability tests conducted on the digital command system are shown in table III. These tests overstressed the digital command system in acceleration, vibration, voltage, and combinations of altitude, temperature, voltage, and time. These overstress tests confirmed an adequate design margin inherent in the digital command system.

Typical reliability tests on other systems and components included such environments as proof-pressure cycling, repeated simulated missions, and system operation with induced contamination. The contamination test was conducted on the reentry control system and the orbital attitude and maneuver system because these systems were designed with filters and pressure regulators which contained small orifices susceptible to clogging.

Some reliability tests were eliminated when Gemini flight data revealed that in some instances qualification tests had actually been overstress tests. This was particularly true with respect to vibration.



All failures which occurred during the reliability tests were analyzed to determine the cause of failure and to establish the required corrective action. Decisions to redesign, retest, or change processes in manufacturing were rendered after careful consideration of the probability of occurrence, mission performance impact, schedule, and cost.

For the most part, the reliability tests were conducted as a continuation of the formal qualification tests on the same test specimens used in the qualification tests after appropriate refurbishment and acceptance testing. When the previous testing expended the test specimen to a state that precluded refurbishment, additional new test units were used.

## 9. QUALITY CONTROL

A rigid quality control system was developed and implemented to attain and maintain the reliability that was inherent in the spacecraft design. This system required flight equipment to be produced as nearly as possible to the qualified configuration.

The unique features of the quality control system which contributed to the success of the Gemini flight program were:

- (1) Configuration control
- (2) Material control
- (3) Quality workmanship
- (4) Rigid inspection
- (5) Spacecraft acceptance criteria

Configuration control is necessary to maintain spacecraft quality; therefore, contractor and customer management developed and implemented a rigid and rapid change-control system which permitted required changes to be documented, approved, implemented, and verified by quality control, with the inspector being fully cognizant of the change before it was implemented on the spacecraft. When a change was considered necessary, and the program impact had been evaluated for design value, schedule, and cost, the proposed change was formally presented to the management change board for approval and implementation. All changes made to the spacecraft were processed through the change board.

Each article of flight equipment was identified by a part number. Components, such as relay panels, tank assemblies, and higher orders of electrical or electronic assemblies, were serialized, and each serialized component was accounted and recorded in the spacecraft inventory at the time it was installed in the spacecraft.

Exotic materials such as titanium, Rene' 41, and explosive materials used in pyrotechnics were accounted for by lots to permit identification of any suspect assembly when it was determined that a part was defective because of material deficiency.

Inspection personnel and fabrication technicians who required a particular skill such as soldering, welding, and brazing were trained and certified for the respective skill and retested for proficiency at regular intervals to retain quality workmanship.

The very strict control of parts and fabricated assemblies was maintained by rigid inspection methods. All deficiencies, discrepancies, or test anomalies were recorded and resolved regardless of the significance that was apparent to the inspector at the time of occurrence. All equipment installations and removals required an inspection approval prior to making or breaking any system interfaces.

Formal spacecraft acceptance reviews were conducted at strategic stages of the spacecraft assembly and test profile. The reviews were conducted with both the customer and the contractor reviewing all test data and inspection records to isolate any condition which occurred during the preceding manufacturing and test activity that could adversely affect the performance of the equipment.

All failures, malfunctions, or out-of-tolerance conditions that had not been resolved were brought to the attention of the management review board for resolution and corrective measures. The reviews were conducted prior to final spacecraft system tests at the contractor's plant immediately prior to spacecraft delivery, and approximately 10 days preceding the impending flight.

## **10. FLIGHT EQUIPMENT TESTS**

A series of tests were conducted on all flight articles to provide assurance that the reliability potential of the design had not been

degraded in the fabrication and handling of the hardware. The tests conducted on flight equipment included:

- (1) Receiving inspection
- (2) In-line production tests
- (3) Predelivery acceptance tests (PDA)
- (4) Preinstallation acceptance tests (PIA)
- (5) Combined spacecraft system test (SST)
- (6) Spacecraft-launch vehicle joint combined system tests
- (7) Countdown

In receiving inspection, critical parts were given a 100-percent inspection that could have included X-ray, chemical analysis, spectrographs, and functional tests.

While the equipment was being assembled, additional tests were performed to detect deficiencies early in manufacturing. Mandatory inspection points were established at strategic intervals during the production process. These were established at such points as prior-to-potting for potted modules and prior-to-closure for hermetically-sealed packages. As an example, certain electronic modules of the onboard computer received as many as 11 functional tests before they went into the final acceptance test.

A predelivery acceptance test verified the functional performance of the equipment and was performed at the vendor's plant in the presence of vendor and government quality control representatives. These tests for the inertial measuring unit included environmental exposure to

vibration and temperature because these environments were considered to be prime contributors to the mechanics of failure. For complex or critical equipment, spacecraft contractor engineering and quality control and government engineering representatives were also present to witness the test for initial deliveries.

Prior to installation in the spacecraft, the unit was given a pre-installation acceptance test to verify that the functional characteristics or calibration had not changed during shipment. This test was conducted identically to the predelivery acceptance test where feasible, except when a difference in test equipment necessitated a change. When differences in test equipment dictated a difference in the testing procedure, the test media (such as fluids, applied voltages, and pressures) were identical, and test data were recorded in the same units of measure in order to compare test results with previous test data. This permitted a rapid detection of the slightest change in the performance of the equipment.

Spacecraft systems tests were performed on the systems after installation in the spacecraft, prior to delivery. They included individual systems tests prior to mating the spacecraft sections, integrated systems tests, simulated flight tests, and altitude chamber tests after mating all of the spacecraft sections. These tests used special connectors built into the equipment to prevent equipment disconnection which would invalidate system interfaces.

Similar systems tests were repeated during spacecraft premate verification at the launch-site checkout facility. After the spacecraft had been electrically connected to the launch vehicle, a series of integrated system functional tests were performed. Upon completion of these tests, simulated flights which exercise the abort mode sequences were conducted in combination with the launch vehicle, the Mission Control Center, the Manned Space Flight Network, and the flight crew.

The countdown was the last in a series of systems functional tests to verify that the spacecraft was ready for flight. It should be pointed out again that any abnormality, out-of-tolerance condition, malfunction, or failure resulting from any of these tests, was recorded, reported, and evaluated to determine the cause and the effect on mission performance.

## **11. FAILURE REPORTING, FAILURE ANALYSIS, AND CORRECTIVE ACTION**

Degradation in the inherent reliability of the spacecraft systems was minimized through the rigid quality control system and a closed-loop failure-reporting and corrective-action system. All failures of flight-configured equipment, during and after acceptance tests, were required to be reported and analyzed. No failure, malfunction, or anomaly was considered to be a random failure. All possible effort was expended to determine the cause of the anomaly to permit immediate corrective action.

Comprehensive failure-analysis laboratories were established at the Kennedy Space Center and at the spacecraft contractor's plant to provide rapid response concerning failures or malfunctions which occurred immediately prior to spacecraft delivery or launch.

However, in cases where the electronic or electro-mechanical equipment was extremely complex, the failed part usually was returned to the vendor when the failure analysis required special engineering knowledge, technical skills, and sophisticated test equipment.

A tabulated, narrative summary of all failures which occurred on the spacecraft and spacecraft equipment was kept current by the prime contractor. This list was continuously reviewed by the customer and the contractor to assure acceptable and timely failure analyses and resulting corrective action. The contractor established a priority system to expedite those failure analyses which were most significant to the pending missions.

A simplified flow diagram of the corrective action system is shown in figure 7. All failures or malfunctions were recorded and reported. A material review board determined the disposition of the failed equipment, and an analysis of the failure was conducted at either the supplier's plant, the prime contractor's plant, or at the Kennedy Space Center, depending on the nature of the condition, the construction of the equipment, and the availability of the facilities at each of the respective locations. When the analysis of a supplier's equipment was conducted

at the prime contractor's plant or at the Kennedy Space Center, the respective supplier's representative was expected to participate in the analysis.

When the failure-analysis report was available, the recommended corrective action was evaluated, and a decision rendered to implement the required corrective action. This may have required management change board action to correct a design deficiency, a change in manufacturing processes, establishment of new quality control techniques, and/or changes to the acceptance-testing criteria. Each change was also evaluated to determine whether qualification status of the equipment had been effected. If the equipment could not be considered to be qualified by similarity, additional environmental tests were conducted to confirm the qualification status.

## **12. UNMANNED FLIGHT TESTS**

The final tests conducted to support the manned missions were the unmanned flights of Gemini I and Gemini II. Gemini I verified the structural integrity of the spacecraft and demonstrated compatibility with the launch vehicle. Gemini II, a suborbital flight, consisted of a production spacecraft with all appropriate onboard systems operating during prelaunch, launch, reentry, postflight, and recovery. Each system was monitored by special telemetry and cameras that photographed the crew station instrument panels throughout the flight. The flight demonstrated the capability of the heat-protection devices to withstand



the maximum heating rate and temperature of reentry. The successful completion of the Gemini II mission, combined with ground qualification test results, formed the basis for declaring the spacecraft qualified for manned space flight.

Subsequent to Gemini XII delivery, the failure history was reviewed to determine how adequate the test program had been in meeting its objectives. A total of 7792 malfunction reports had been written on spacecraft-type equipment. These reports were sufficiently significant to require action by a Material Review Board, which was composed of more than one engineering discipline. Of this total, 5671 were primary equipment failures, 1474 were induced failures, and 647 were failures such that the cause could not be determined. These malfunctions are shown in table IV. Of the 7792 malfunction reports analyzed, 2392 were written on non-flight-configured equipment used for qualification, reliability, life, and engineering tests, and 5400 were written on flight-configured equipment.

The predelivery acceptance (PDA) and preinstallation acceptance (PIA) tests were designed to detect equipment failures at the earliest possible time in the spacecraft buildup sequence. Of the total flight-hardware malfunctions analyzed, 52 percent occurred in PDA testing; another 36 percent occurred in PIA testing. Thus, 88 percent of all flight hardware malfunctions occurred during the conduct of these tests before the equipment was installed in the spacecraft.

This indicates that the acceptance tests effectively accomplished the purpose for which they were designed.

TABLE I.- GEMINI III RELIABILITY ESTIMATES

	Planned mission success (a)	Gross mission success (b)
Electrical power	0.999	0.999
Guidance and control Propulsion OAMS RCS	0.952 0.9602 .9919	0.991 0.9992 .9919
Electronics	.967	.9998
Communications	0.999	0.999
Instrumentation	0.999	0.999
Environmental control	0.989	0.989
Landing	0.985	0.985
Sequentials, rockets, and pyros	0.957	0.988
TOTAL	0.856	0.951

<sup>a</sup>Planned mission success is having the spacecraft function as necessary and perform the objectives of the mission as established in the mission directive.

<sup>b</sup>Gross mission success is inserting the spacecraft into orbit, having the capability of completing the prescribed orbital duration, and recovering the flight crew and spacecraft.



TABLE III.- DIGITAL COMMAND SYSTEM RELIABILITY TESTS

Environments	Qualification tests	Overstress tests
Acceleration	7.2g in 326 sec	9.0g in 326 sec
Random vibration	Overall acceleration level of 12.6g rms for 15 min per axis	Overall acceleration level of 15.6g rms for 3 min per axis
Combined altitude, high temperature, high voltage	None	Pressure, $1.7 \times 10^{-6}$ psia Temperature, 200° F Voltage, 36 Vdc
Combined low temperature, low voltage	None	Temperature, -60° F Voltage, 17 Vdc
Applied high voltage	30.5 to 33.0 Vdc	36 Vdc
Applied low voltage	18.0 to 20.0 Vdc	17 Vdc

TABLE IV.- GEMINI SPACECRAFT SYSTEM MALFUNCTION, CUMULATIVE TEST ACTIVITY

Class	DEV	CTU	ESTU	CIMU	EVAL	QUAL	DEM	SMR	OSR	LIFE	PDA	PIA	SST	PIA	SST	FLT	PME	Total
Project total																		
Primary	224	47	12	--	195	1099	33	5	101	19	2217	1236	270	36	101	18	38	5671
Induced	33	21	6	1	83	349	8	3	25	3	439	369	82	7	30	3	12	1474
Undetermined	7	11	1	--	24	47	5	--	8	2	166	281	52	10	20	8	5	647
Total	284	79	19	1	302	1495	46	8	134	24	2822	1886	404	53	151	29	55	7792

Activity Codes

DEV - Development Test  
 CTU - Compatibility Test Unit  
 ESTU - Electronic System Test Unit  
 CIMU - Complete Instrumentation Mock-up  
 EVAL - Evaluation, Compatibility, and Integration  
 QUAL - Qualification of Parts and Subsystems  
 DEM - Demonstration and Spacecraft Level Qualification  
 SMR - Simulated Mission Reliability  
 OSR - Overstress Reliability Tests  
 LIFE - Life and Endurance Tests  
 PDA - Predelivery Acceptance Tests  
 PIA - Preinstallation Acceptance - St. Louis  
 SST - Spacecraft System Test - St. Louis  
 PIA - Preinstallation Acceptance - Cape  
 SST - Spacecraft System Test - Cape  
 FLT - Flight  
 PME - Post-Mission Evaluation

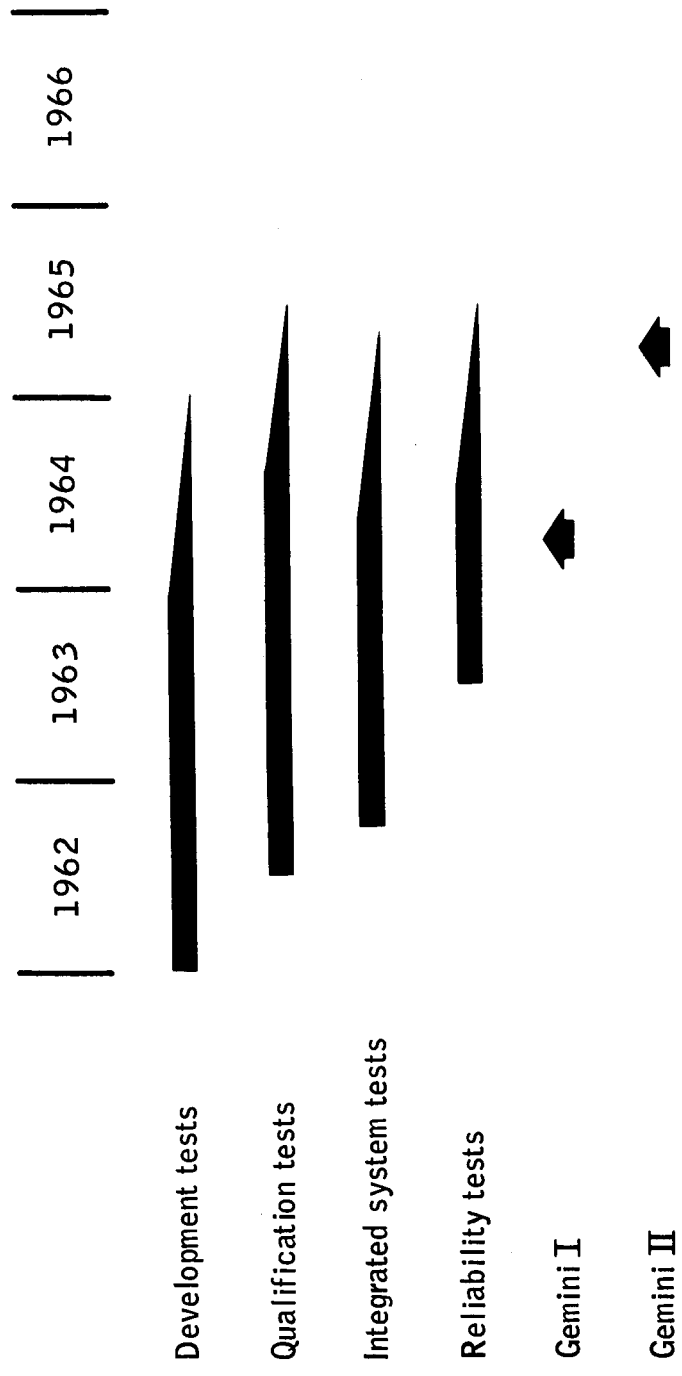


Figure 1.- Gemini test program.

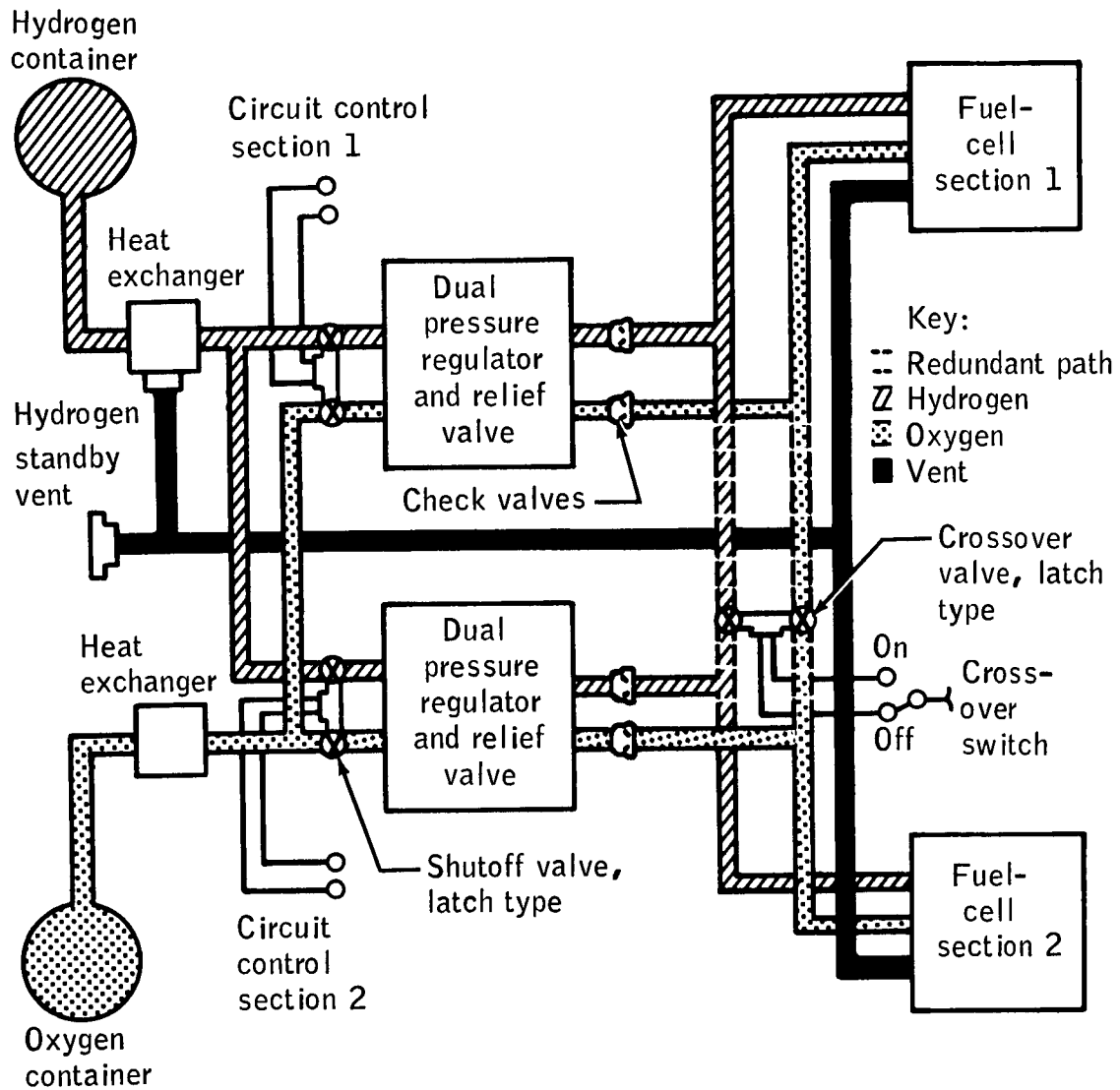


Figure 2.- Gemini reactant supply system.



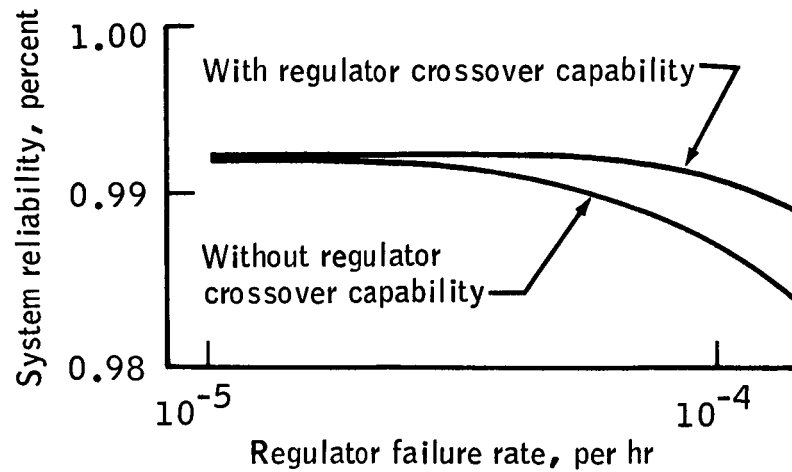


Figure 3.- Gemini fuel cell power system reliability - 2-week mission.

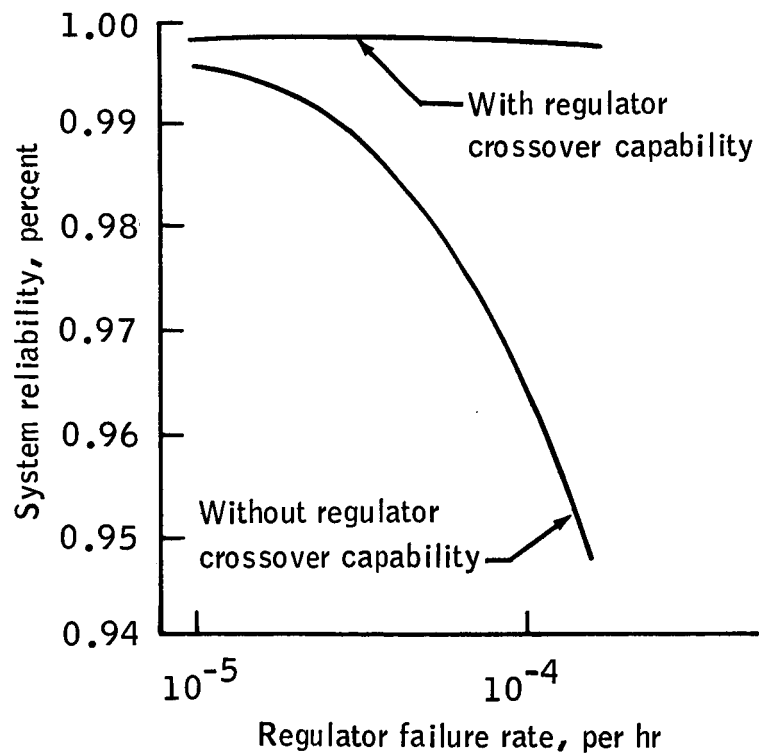


Figure 4.- Gemini fuel cell power system reliability - 2-day mission.

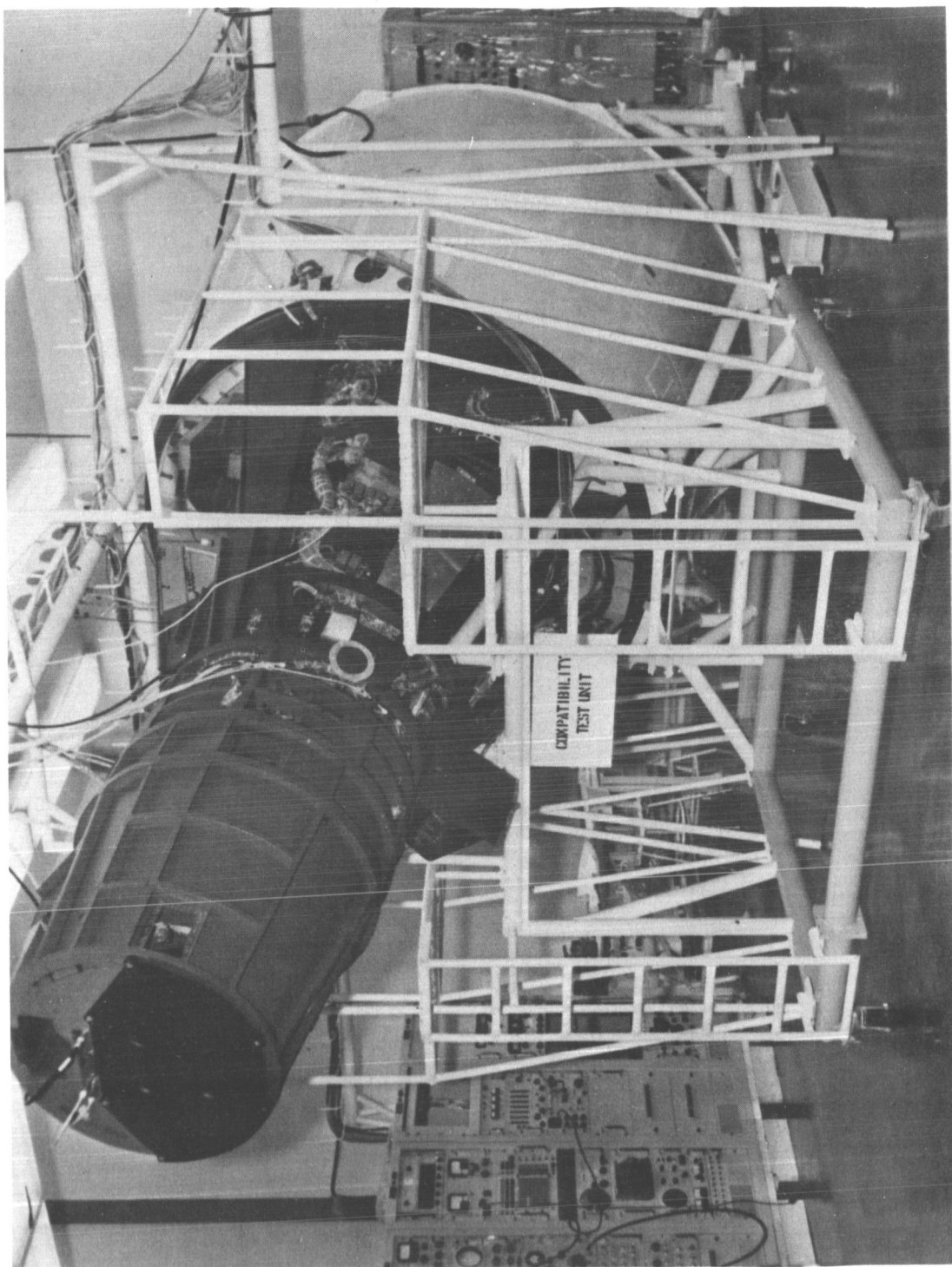


Figure 5.- Gemini compatibility test unit.

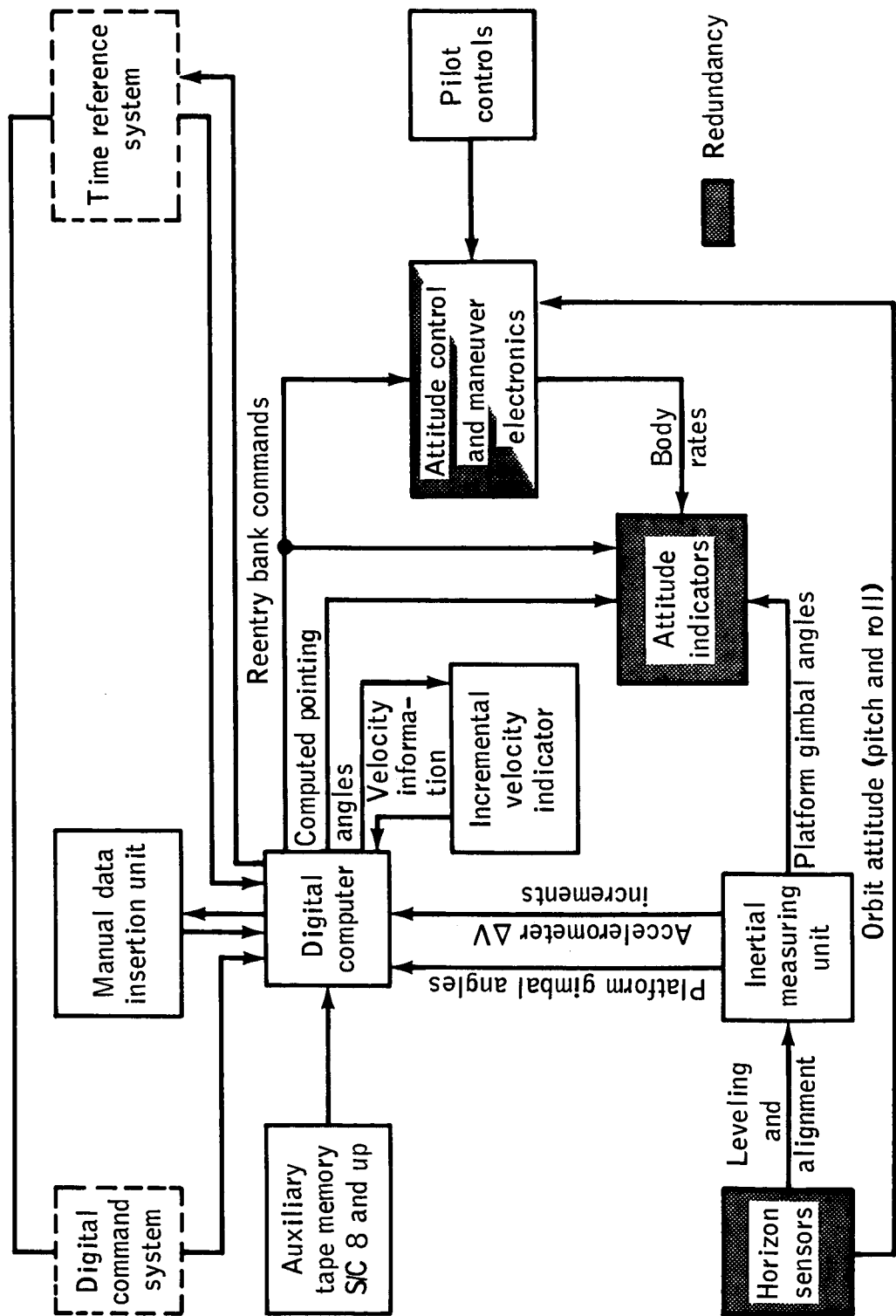


Figure 6.- Gemini guidance and control system.

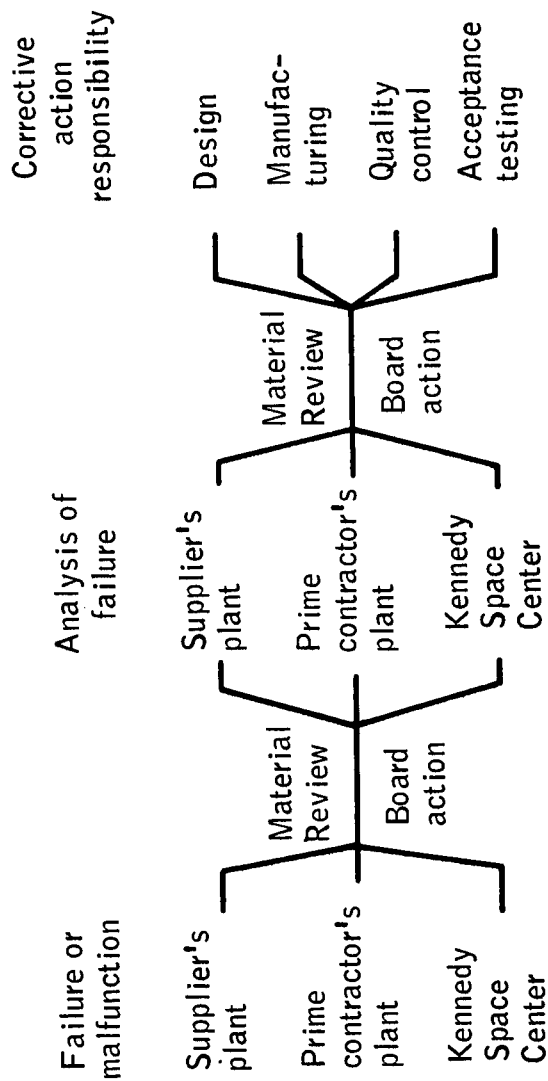


Figure 7.- Gemini corrective action flow schematic.